Initial Results from the New Submicron X-Ray Diffraction Instrument on Beamline 7.3.3

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INTRODUCTION

Extremely high mechanical stresses exist in passivated (buried) metal conductors that connect modern microelectronic devices. These stresses are caused by thermal mismatch, by confinement, and by current flow. The effects of these stresses are to cause failure, from simple delamination to the more complicated case of electromigration where high electrical current density results in material transport, the formation of voids in the metal conductor lines and subsequent open circuit failure of the interconnect (1). These problems are of great importance for semiconductor manufacturers. However, to date no tool has been available to study stresses on the micron scale in individual interconnects. Stress on the macro scale is routinely studied on arrays of interconnect lines with x-ray diffraction. Here at the ALS we have instrumented a beam line with a new machine that is capable of measuring stress on the micron scale by means of x-ray micro diffraction. This instrument was commissioned in December 1999 and this note describes the first results from it.

EXPERIMENTAL

A new micro diffraction end station has been installed on the bend magnet beamline 7.3.3. More details of the instrumentation have been given in another abstract published within this volume (2). Carrying out x-ray diffraction on the micron scale requires different instrumental considerations compared to the more conventional macro x-ray diffraction. First there is the problem of finding the sample. More critical is the issue of recording diffraction curves without angular motion of the sample. Well-constructed modern diffractometers have a sphere of confusion of tens of microns. Any sample rotation would move a micron-sized sample out of the sub-micron sized beam. We have addressed the first problem by using white light to illuminate the sample – the Laue pattern generated by the micro crystal establishes its location and orientation. Keeping the sample fixed and scanning the wavelength addresses the second problem.

The new instrument is capable of illuminating the sample with a focused X-ray spot down to sub-micron dimensions (0.8 x 0.8 microns fwhm). This focused x-ray spot can be either white or monochromatic x-rays with an energy range of ~6-14KeV. The ability to switch between white and monochromatic light is achieved by inserting a 4-crystal monochromator into the beam. X-ray micro-focusing is achieved by means of a Kirk Patrick-Baez mirror pair (3). The diffracted x-rays are detected by a 4K x 4K CCD (Bruker) with a 9x9 cm view area mounted on a detector arm that can be positioned around the sample. The sample is mounted on a precision x-y translator to allow for the sample to be scanned under the micro beam.

The micro diffraction technique that has been developed consists of illuminating the sample with the submicron broad bandpass (white) beam and collecting the Laue reflections using the large area CCD detector. As the crystal structure of the sample is known, the Laue patterns yield the orientation of the micro-crystals. Slight displacements of the Laue spots from their "correct" (distortionally free) positions allows for the full deviatoric (distortional) strain tensor (4) of the micro-crystal to be directly derived. The dilatational component of the strain is obtained by switching to monochromatic beam and making energy scans on selected reflections.

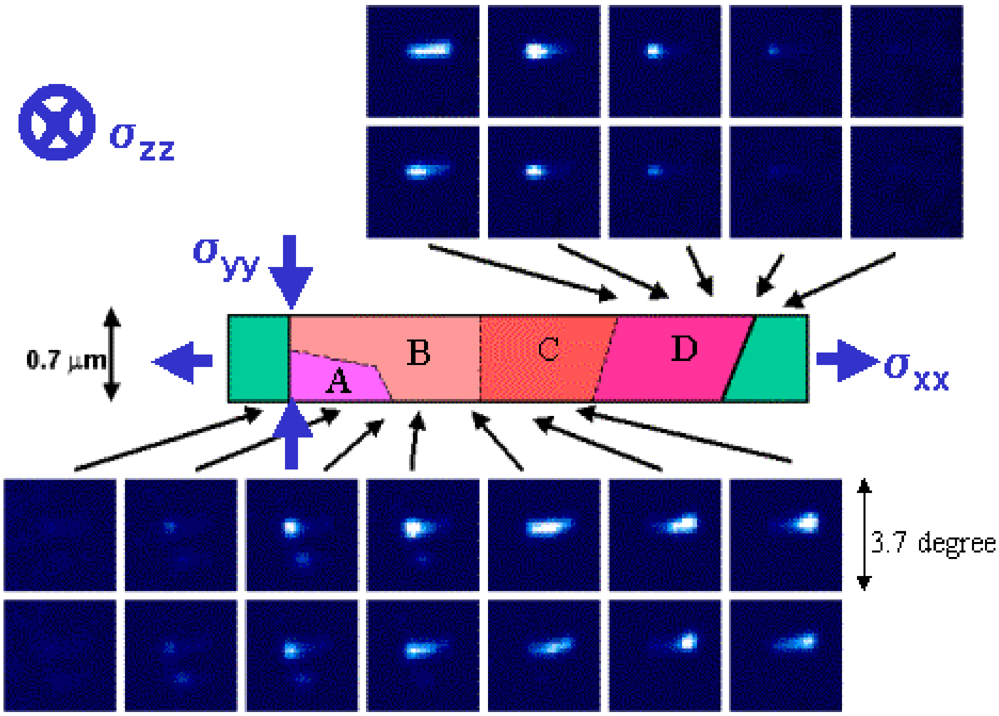

Figure 1. Diffraction spots from sub grains in a 3.8 x 0.7 μm grain of an Al interconnect studied by following the position and shape of the (111) reflection in white X-ray micro-beam mode.

INITIAL RESULTS

Our first sample was a passivated 0.7 micron wide, 0.75 micron thick Al interconnect wire. Laue patterns were recorded as we scanned the sample in front of the micro-beam. Figure 1 shows the series of Laue spots of the 111 reflection that were recorded on a 3.8 micron length of the interconnect line. 24 Laue patterns were recorded corresponding to a 2x12 array over the sample on 0.4 micron centers. From the detailed change in the 111 Laue spot, the 2 dimensional grain structure of the interconnect pattern can be inferred as shown in Figure 1. This section of interconnect is made up of 4 grains (A, B, C and D) that are angularly displaced from each other. The Laue indexing code produces the full orientation matrix for each grain. The small grain A is angularly displaced from the adjacent grain B by 4.92 degrees. This is indicated in the lower left hand Laue images where two 111 spots can be seen corresponding to the grains A and B. The grains B, C and D, as indicated by the Laue spots images are all very close in alignment. The misalignment of B-C and C-D are 0.67 and 0.56 degrees respectively. The analysis code is able to determine the displacement of the spots from their nominal strain free predicted positions. This yielded Figure 2, which shows the deviatoric (distortional) stress along the length of this 3.8 micron section. The data indicates that the line is in tension along its length and compression in the normal directions. The very similar stress in the normal directions is consistent with the square cross section. There also appear to be stress variations within the BCD subgrain segment of magnitude 30-40MPa. We believe these are real as they are above the sensitivity of the instrument that has been determined to be 20MPa for Al – this corresponds to a crystal d spacing accuracy measurement of $2x10^{-4}$.

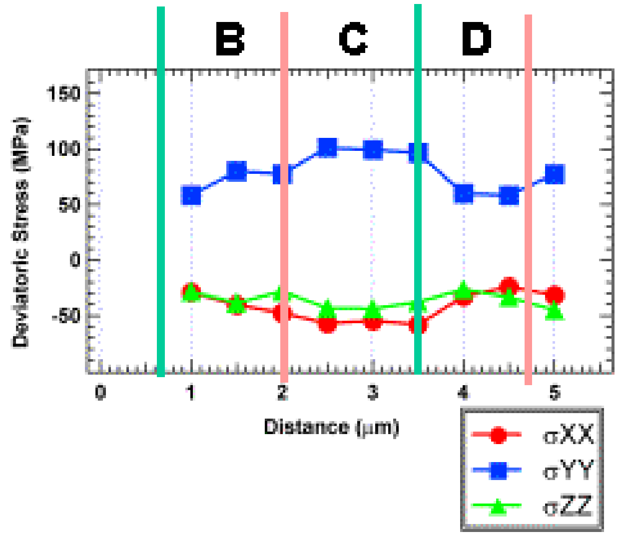

Figure 2. Variation of deviatroric stress along the length of the 3.8 mircon grain of figure 1.

We have also studied the evolution of the deviatoric stress components in a single Al grain within an interconnect line during thermal cycling. In figure 3, the sample temperature was raised to 225 °C, followed by cooling to room temperature. As the wire is cooled a large tensile stress developed in the direction along the wire, whereas the normal component of the distortional stress becomes compressive. The data demonstrate the stability and sensitivity of the new instrument in its ability to measure stress over long periods of time (1 day) on micron-sized samples.

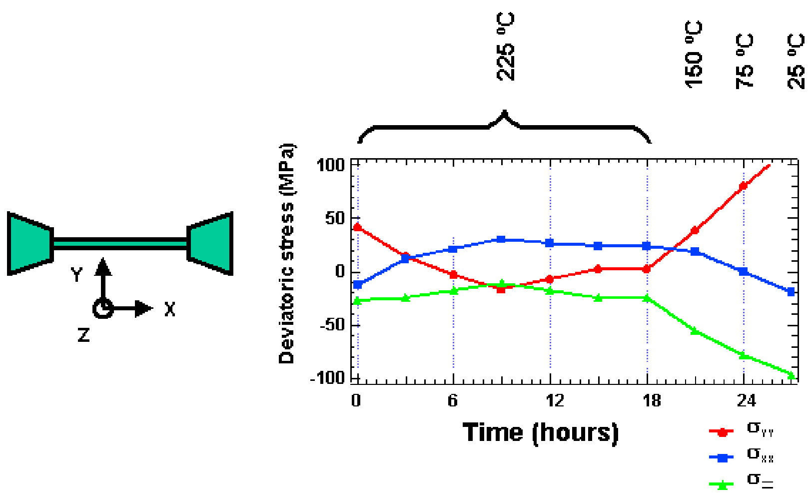

Figure 3. Evolution of the deviatoric stress components in a single Al grain within an interconnect line during a thermal cycling experiment. The schematic on the left represents the thin wire with contact pads and the orientation vectors.

ACKNOWLEDGEMENTS

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